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**FINAL REPORT**

**THE ECONOMIC BENEFIT OF PEA AND CANOLA IN CROP  
ROTATIONS**

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**Project Name:** The Economic Benefit of Pea and Canola in Crop Rotations

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#### **a) ABSTRACT/SUMMARY**

Canola-wheat-barley, pea-wheat-barley and wheat-wheat barley rotations were compared for their affect on cereal yields and grain N content. Wheat grown on pea and canola stubble yielded higher and had higher grain N contents than wheat grown on wheat stubble. The benefit was not apparent in the barley crop. Only a small portion of the yield benefit was identified and was attributed to reduced leaf diseases and improved N availability. A landscape-scale study identified differences between the rotations not identified in a small-plot study. Differences between landform elements did not explain differences in yield and grain quality among the crop rotations.

#### **b) EXECUTIVE SUMMARY**

Producers and researchers have observed that cereal crop yields often are higher when the cereal is sown on pulse crop stubble than on cereal crop stubble. Often it is assumed that this yield benefit is due to the N fixed by the legume and left in the soil as root and shoot residues being made available to the next year's crop. However, in recent years it has become apparent that a similar benefit can be obtained by including non-legume broadleaf crops in intensive cereal rotations. An analysis of the Manitoba crop insurance database revealed that the average yield advantage of growing wheat after pea and canola, compared to wheat after wheat was 11% for pea and 8% for canola (Bourgeios and Entz, 1996). In the case of canola, yield advantages to the cereal can not be due to an N benefit because canola does not fix atmospheric N, but rather are due to non-N benefits, including interruptions of disease cycles, and reductions in weed densities in the succeeding cereal.

In the spring of 1996, the current study was initiated to investigate and compare the benefit of including pea and canola in rotation to the succeeding wheat and barley crops in the Black soil zone. If the benefit of including pea in a cereal intensive rotation is largely due to non-N related factors, it is expected that a non-legume broadleaf crop, such as canola, could provide the same benefits as the pea. In this study, we also investigate the differences in the rotation benefit between small plots and landscape-scale plots to further refine our research approach. In addition, the influence of topographic variation on the expression of rotation benefits was examined by comparing differences in soil and plant variables between shoulder and footslope positions in the landscape-scale experiments. Variables that were measured included: inorganic N and soil water prior to sowing; atom %  $^{15}\text{N}$  excess (N availability); leaf and root disease incidence; and dominant weed populations.

A small-plot experiment and a landscape-scale experiment, with pea-wheat-barley, canola-wheat-barley, and wheat-wheat-barley rotations, were established at each of two field sites, located near St. Louis and Birch Hills in 1996. Two additional sites were established near Alvena and Prince Albert in 1997. The Alvena site was abandoned in 1998 when the producer decided to graze elk on the land. This report only includes data from the St. Louis, Birch Hills and Prince Albert sites.

In the landscape-scale study, a clear yield benefit existed in the second rotation phase when wheat was grown after pea and canola, compared to when wheat was grown after a wheat crop. Wheat grain yields were approximately 12.5 % higher ( $200 \text{ kg ha}^{-1}$ ) in the pea-wheat and canola-wheat rotations than in the wheat-wheat rotation. All three sites exhibited the same tendency. The small-plot study showed the same tendency for

lower wheat yields in the wheat-wheat rotation compared to the two rotations containing broadleaf crops, but these differences were not statistically significant. Of the soil and plant factors that were measured in the landscape-scale study, soil inorganic N was lower, and leaf diseases and wild oat densities were higher in the wheat-wheat rotations compared to the other two rotations. In addition, measurements of N availability to the crop indicated that more N was available to wheat grown after pea, than to wheat grown after either canola or wheat. However, when an analysis of covariance was performed to identify those factors responsible for the differences in grain yields among the different crop rotations, only a very small amount of the rotation effect could be attributed to any of these factors. At St. Louis and Prince Albert, only 12 % of the total rotation effect could be identified; 88% of the rotation effect remained unaccounted for. At St. Louis the rotation effect on yield was split equally between the N benefit (atom %  $^{15}\text{N}$  excess) and non-N benefit (leaf diseases). At Prince Albert, the majority (11 of the 12 % total) of the rotation effect on yield was the result of a reduction in leaf diseases in the pea-wheat and canola-wheat rotations compared to the wheat-wheat rotation. At Birch Hills, differences in the incidences of leaf diseases played a larger role in determining grain yield associated with the different rotations, but still only accounted for 27 % of the total rotation effect. At this site 1 % of the rotation effect on grain yields was attributable to a N benefit.

In the small-plot study, none of the soil and plant factors measured reliably predicted the slight differences in grain yield that were observed. Furthermore, the patterns for soil inorganic N, atom %  $^{15}\text{N}$  excess, leaf diseases and wild oat incidences, associated with the different crop rotations were different between the landscape-scale

and small-plot studies. Clearly, by including plots in the landscape-scale study with topographic variation typical of producer's land in the Black soil zone, different plant and soil responses are obtained than when crops are grown on small homogeneous plots.

In contrast to several other studies, the effect of the different rotations on grain yield did not carry over into the third (barley) rotation phase. Although there was a tendency for barley grain yield to be higher in the pea-wheat-barley rotation than the other two rotations, the differences were not statistically significant.

Crop yields at each of the three field sites, responded very differently to the two landform elements analysed. At St. Louis, the footslope positions supported the highest wheat yields in the second rotation phase for all three crop rotations. Only soil inorganic N and soil water prior to seeding were consistently higher on the footslopes than the shoulders. However, because of seasonal precipitation and N fertilization, it is unlikely that these two factors alone could account for the higher yields at this site. At Birch Hills and Prince Albert, there were no consistent patterns for wheat yield between the footslope and shoulder positions. None of the soil or plant factors measured varied consistently between the different landscape positions at either site. It appears that very patchy responses across the landscape interfered with the ability to detect differences between landscape positions.

In the third rotation (barley) phase, each of the sites exhibited very different responses for barley grain yield that were not explained by associated differences in soil resources or weed and disease populations.

Overall, grain yields in the second phase of the rotation were affected by the different crop rotations. In general, a similar yield benefit was achieved by sowing wheat

in pea or canola stubble compared to sowing wheat in wheat stubble. However, the exact cause of the benefit to yield was elusive. Only a small percentage of the rotation benefit (between 12 and 28 %) could be attributed to specific N or non-N benefits. Conducting the experiments on large plots of land (4 ha.) enabled us to detect differences in yields associated with the different crop rotations that could not be detected using small homogeneous plots. However, comparing this study to other landscape-scale studies conducted on smaller land bases (1 ha.), it appears that the larger study areas used here were not appropriate for this type of agronomic research. It seems that too much variability associated with the landscape was introduced using the present approach and that this variability could not be properly 'controlled' or accounted for using traditional statistical methods (analysis of variance).

## c) TECHNICAL REPORT

### Materials and Methods:

#### *Site characterization:*

Research sites were established on producer's land near St. Louis and Birch Hills in 1996, and Prince Albert in 1997. Originally a fourth site was established in 1997 near Alvena, but was eliminated from the study in 1998 because of the producer's decision to graze elk on the research land. Although measurements were made at the Alvena site throughout 1997, this data will not be reported because the study was not continued through the second and third rotation years.

The terrain at the three remaining sites varied from hummocky to undulating. Soils at St. Louis, and Birch Hills are mainly orthic Chernozems of the Hoey and Blaine Lake associations, with significant occurrence of soils of the Gleysolic order in the lower slope positions and soils of the Regosolic order in the upper slope positions. These soils developed on a silty-textured lacustrine parent material. Soils at the Prince Albert site are mainly Orthic Chernozems of the Meota association, with a fine sand to sandy loam texture and notable erosion on the upper slopes and knolls.

Basic soil characterization for each site is provided in Table 1. Soil pH and electrical conductivity was measured using a soil to solution ratio of 1:1. Total C and N were determined on finely ground soil samples using a LECO C-N-S analyser.  $\text{NH}_4^+$  and  $\text{NO}_3^-$  were measured on soil samples extracted with 2 M KCl using a Technicon AutoAnalyzer II System (Labtronics Inc., Tarrytown, NY). Because the amounts of  $\text{NH}_4^+$  measured were very small relative to the  $\text{NO}_3^-$  (and within the experimental error of the apparatus) the two values were combined and reported as available inorganic N. Soil

Table 1. Soil physical and chemical properties (median and interquartile range) at the three field sites.

| Site /<br>Landform       | Soil                                       |                                          | Electrical conductivity |           |           |           | pH        |           | Total C   |           | Total N           |
|--------------------------|--------------------------------------------|------------------------------------------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-------------------|
|                          | Bulk<br>density<br>†<br>g cm <sup>-3</sup> | water<br>0-60<br>cm<br>g g <sup>-1</sup> | 0-30 cm                 | 30-60 cm  | 0-30 cm   | 30-60 cm  | 0-30 cm   | 30-60 cm  | 0-30 cm   | 30-60 cm  | g g <sup>-1</sup> |
| <i>St. Louis</i>         |                                            |                                          |                         |           |           |           |           |           |           |           |                   |
| Shoulder                 | 1.49                                       | 27.0±0.47                                | 16.6±6.7                | 22.4±19.5 | 7.67±0.42 | 8.25±0.39 | 7.58±0.39 | 3.06±0.99 | 1.67±0.72 | 0.28±0.09 | 0.12±0.04         |
| Footslope                |                                            | 28.1±0.39                                | 15.3±8.3                | 19.0±15.8 | 7.58±0.39 | 8.06±0.42 |           | 3.11±1.16 | 1.73±0.82 | 0.27±0.11 | 0.12±0.06         |
| <i>Birch Hills</i>       |                                            |                                          |                         |           |           |           |           |           |           |           |                   |
| Shoulder                 | 1.49                                       | 24.9±0.36                                | 14.9±8.4                | 20.7±11.5 | 7.58±0.72 | 8.35±0.42 | 7.58±0.72 | 2.66±1.74 | 2.23±0.66 | 0.24±0.16 | 0.15±0.05         |
| Footslope                |                                            | 27.4±0.67                                | 13.3±5.4                | 13.8±9.4  | 7.30±0.58 | 7.79±0.77 | 7.30±0.58 | 3.78±1.90 | 2.05±0.95 | 0.33±0.17 | 0.17±0.06         |
| <i>Prince<br/>Albert</i> |                                            |                                          |                         |           |           |           |           |           |           |           |                   |
| Shoulder                 |                                            | 10.7±0.10                                | 61.7±12.7               | 48.2±10.3 | 6.80±0.90 | 7.20±0.80 | 6.80±0.90 | 0.77±0.25 | 0.29±0.09 | 0.06±0.01 | 0.03±0.00         |
| Footslope                | 1.73                                       | 13.3±0.73                                | 74.2±42.7               | 53.5±14.9 | 5.80±0.85 | 6.20±0.20 | 5.80±0.85 | 1.77±0.57 | 0.52±0.38 | 0.15±0.05 | 0.05±0.02         |

† Bulk density estimates were similar between landform complexes.

‡ Soil inorganic nitrogen

inorganic N was calculated on a dry-weight basis and was adjusted for the average bulk density at each site. Moisture content was determined gravimetrically. Bulk density was assessed with the core method (Blake and Hartge, 1986).

Cropping history at the sites included mainly wheat, barley, and canola in the years prior to the study, with barley grown as the most recent crop at all sites.

### ***Experimental design:***

#### **Landscape study:**

Pea (pea-wheat-barley rotation), canola (canola-wheat-barley rotation), and wheat (wheat-wheat-barley rotation) plots were established in 30-m  $\times$  80-m plots in a randomized complete block design with five replicates (Fig. 1). A systematic grid with 10-m spacing was superimposed across all plots on each study site. A topographic survey was conducted at each grid point to determine elevational and horizontal coordinates. This information was used to calculate a digital elevation model, that was used to generate slope variables (Pennock et al., 1987, 1994). Ultimately, the slope variables were used to identify the shoulder and footslope landform elements.

#### **First rotation phase**

No tillage operations were performed in the fall preceding the first rotation phase of the study. In the spring of 1996, the St. Louis and Birch Hills sites were cultivated with a medium-duty cultivator, and then harrow packed. In the spring of 1997, 0.5 L ha<sup>-1</sup> glyphosate (Roundup) was applied to control weeds that emerged prior to seeding at the Prince Albert site and substituted for pre-seeding tillage.

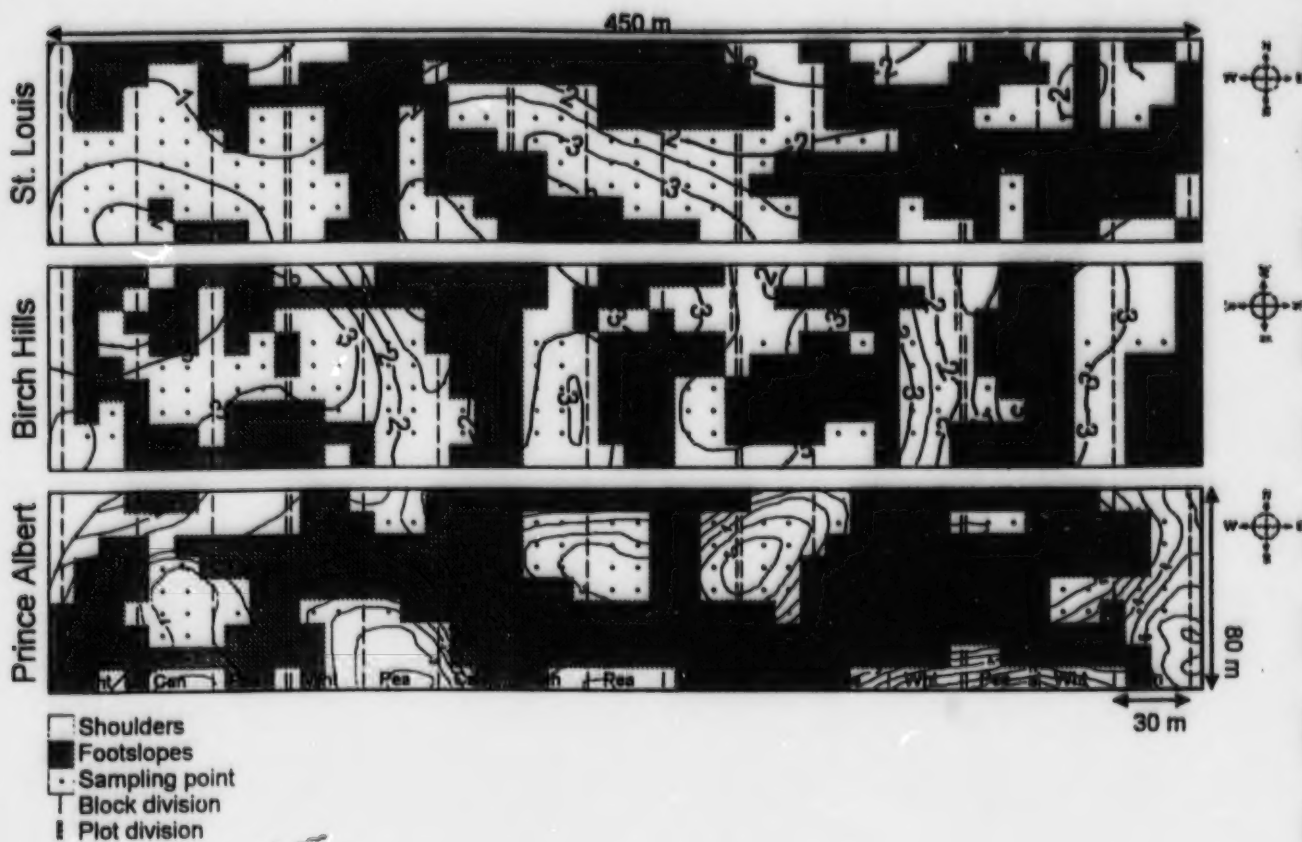


Figure 1. Landscape-scale plot designs. The corresponding small-plot study was established along the east edge of the landscape-scale plots at St. Louis and Prince Albert and along the north edge of the plots at Birch Hills.

The first rotation phase crops were seeded in the last week of May at all of the sites. The St. Louis and Birch Hills sites were seeded with a 12.2-m hoe air-drill supplied by Flexi-Coil (Flexi-Coil Ltd., Saskatoon, SK) and operated by Flexi-Coil technicians. A 4.3-m hoe press drill was used to sow all crops at the Prince Albert site. 'Highlight' pea, inoculated with a commercial *Rhizobium* inoculant (MicroBioRhizogen Corp, Saskatoon, SK), '45A71' *Brassica napus* (L.) canola, and 'Katepwa' (St. Louis and Birch Hills) and 'Teal' (Prince Albert) hard red spring wheat (*Triticum aestivum* L.) were sown. Seeding rates were 200 kg ha<sup>-1</sup> for pea, 5 kg ha<sup>-1</sup> for canola, and 100 kg ha<sup>-1</sup> for wheat. Five kg N ha<sup>-1</sup> and 11 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> were applied as mono-ammonium phosphate in the seed row during all seeding operations at all sites. At the St. Louis and Birch Hills sites, urea was side-banded at a rate of 55 kg N ha<sup>-1</sup> in the canola plots and 50 kg N ha<sup>-1</sup> in the wheat plots. At Prince Albert, liquid ammonium nitrate was side-banded relative to the seed row in the canola and wheat plots at rates respective rates of 70 and 60 kg N ha<sup>-1</sup>.

Grassy and broadleaf weeds in the pea and canola plots were controlled with postemergent applications of imazethapyr (Pursuit) or imazamox (Odyssey). Imazethapyr was tank-mixed with clethodim (Select) at St. Louis and Prince Albert for more complete control of wild oats and volunteer barley. A postemergent application of tralkoxydim (Achieve) tank-mixed with bromoxynil + MCPA (Buctril) was used to control grassy and broadleaf weeds in wheat plots at St. Louis and Birch Hills. Fenoxaprop-p-ethyl + MCPA + thifensulfuron methyl (Laser DF) was used to control grassy and broadleaf weeds in wheat plots at Prince Albert. All herbicides were applied with a high-clearance field sprayer at recommended stages and rates. A preharvest

application of glyphosate (Roundup) was applied with a tractor-drawn field sprayer at Prince Albert to control weeds and unify maturity across all plots.

#### Second rotation phase (wheat)

All pre-seeding tillage operations, fertilization, seeding and herbicide applications were performed by the producer, using the producer's equipment. Pre-seeding tillage operations at the St. Louis and Birch Hills sites in 1997 included one pass with a tandem disc just prior to sowing. The St. Louis and Birch Hills sites were seeded to wheat on May 20<sup>th</sup>, 1997 with a 10-m hoe air-drill. Urea was side-banded relative to the seed row at a rate of 55 kg N ha<sup>-1</sup>. Pre-seeding tillage operations at the Prince Albert site in 1998 included a pass with a heavy-duty cultivator to band anhydrous ammonia at a rate of 60 kg N ha<sup>-1</sup>. The Prince Albert site was seeded with a discer on May 9<sup>th</sup>, 1998. The seeding rate for wheat was 100 kg ha<sup>-1</sup> at all sites. Five kg N ha<sup>-1</sup> and 11 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> were applied as mono-ammonium phosphate in the seed row during seeding operations at all three research sites.

At St. Louis and Birch Hills, clodinafop-propargyl (Horizon) was applied for postemergent control of wild oats. Dicamba + mecoprop + MCPA A (Target) at St. Louis and Prince Albert, and thifensulfuron methyl + tribenuron methyl (Refine Extra Toss-N-Go) tank-mixed with MCPA at Birch Hills, were applied for postemergent control of broadleaf weeds. All herbicides were applied with a high-clearance or tractor-drawn field sprayer at recommended stages and rates.

#### Third rotation phase (barley)

As was the case in the second rotation phase, all pre-seeding tillage operations, fertilization, seeding and herbicide applications were performed by the producer, using the producer's equipment. The St. Louis and Birch Hills sites were cultivated in the fall prior to the 1998 growing season. 'Stander' barley was seeded on May 11<sup>th</sup>, 1998 at St. Louis at a rate of 90 kg ha<sup>-1</sup> using a 12-m air seeder. 'Stein' barley was seeded on May 7<sup>th</sup>, 1998 at the Birch Hills site at a rate of 100 kg ha<sup>-1</sup> using a 17-m air seeder. A fertilizer blend of 60 kg N ha<sup>-1</sup>, 11 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, 3 kg S ha<sup>-1</sup> and 5 kg K ha<sup>-1</sup> was applied at St. Louis. At Birch Hills the fertilizer blend used was 50 kg N ha<sup>-1</sup>, 11 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, 3 kg S ha<sup>-1</sup>, 5 kg K ha<sup>-1</sup> and 0.6 kg Cu ha<sup>-1</sup>. At both sites the fertilizer was applied with the seed and seeding was immediately followed with harrow-packing. Pre-seeding tillage operations at Prince Albert site in the spring of 1999 included a pass with a heavy-duty cultivator to band anhydrous ammonia at a rate of 60 kg N ha<sup>-1</sup>. The Prince Albert site was seeded to 'Manley' barley on May 23<sup>rd</sup>, 1999, at a rate of 90 kg ha<sup>-1</sup> with a discer. A fertilizer blend of 7 kg N ha<sup>-1</sup>, 28 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, and 14 kg S ha<sup>-1</sup> was applied the seed. 2,4-DB (Cobutox 600) was applied at St. Louis, tralkoxydim + clopyralid + MCPA E (Prevail) was applied at Birch Hills, and fenoxaprop-p-ethyl (Puma Super), thifensulfuron methyl + tribenuron methyl (Refine Extra) and MCPA ester was applied at Prince Albert to control post-emergent broadleaf weeds.

### **Small-plot study:**

Pea (pea-wheat-barley rotation), canola (canola-wheat-barley rotation), and wheat (wheat-wheat-barley rotation) plots were established in 3-m  $\times$  20-m plots in a randomized complete block design with eight replicates (Fig. 2).

#### First rotation phase:

Small-plots were sown using a 1.5-m double-disc press drill. The same cultivars of pea, canola and wheat were sown at the same rates as those sown in the landscape-scale study. However, because of the availability of equipment, the plots were fertilized differently from the landscape-scale plots in the first year. The same rates of fertilizers were applied but using different equipment. At the St. Louis site, ammonium nitrate was broadcast and incorporated at a rate of 55 kg N ha<sup>-1</sup> in the canola plots and 50 kg N ha<sup>-1</sup> in the wheat plots immediately after seeding. At the Birch Hills site 50 kg N ha<sup>-1</sup> of urea was banded across the canola and wheat plots four days prior to seeding. The Prince Albert small plots received a surface application of ammonium nitrate at rates of 70 kg N ha<sup>-1</sup> in the canola plots and 60 kg N ha<sup>-1</sup> in the wheat plots. Five kg N ha<sup>-1</sup> and 11 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> were applied as mono-ammonium phosphate in the seed row during all seeding operations at all sites.

Herbicide applications were the same as for the landscape-scale studies.

#### Second and third rotation phases:

Small plots were seeded and managed in the same manner as the landscape-scale plots in the second and third rotation phases.

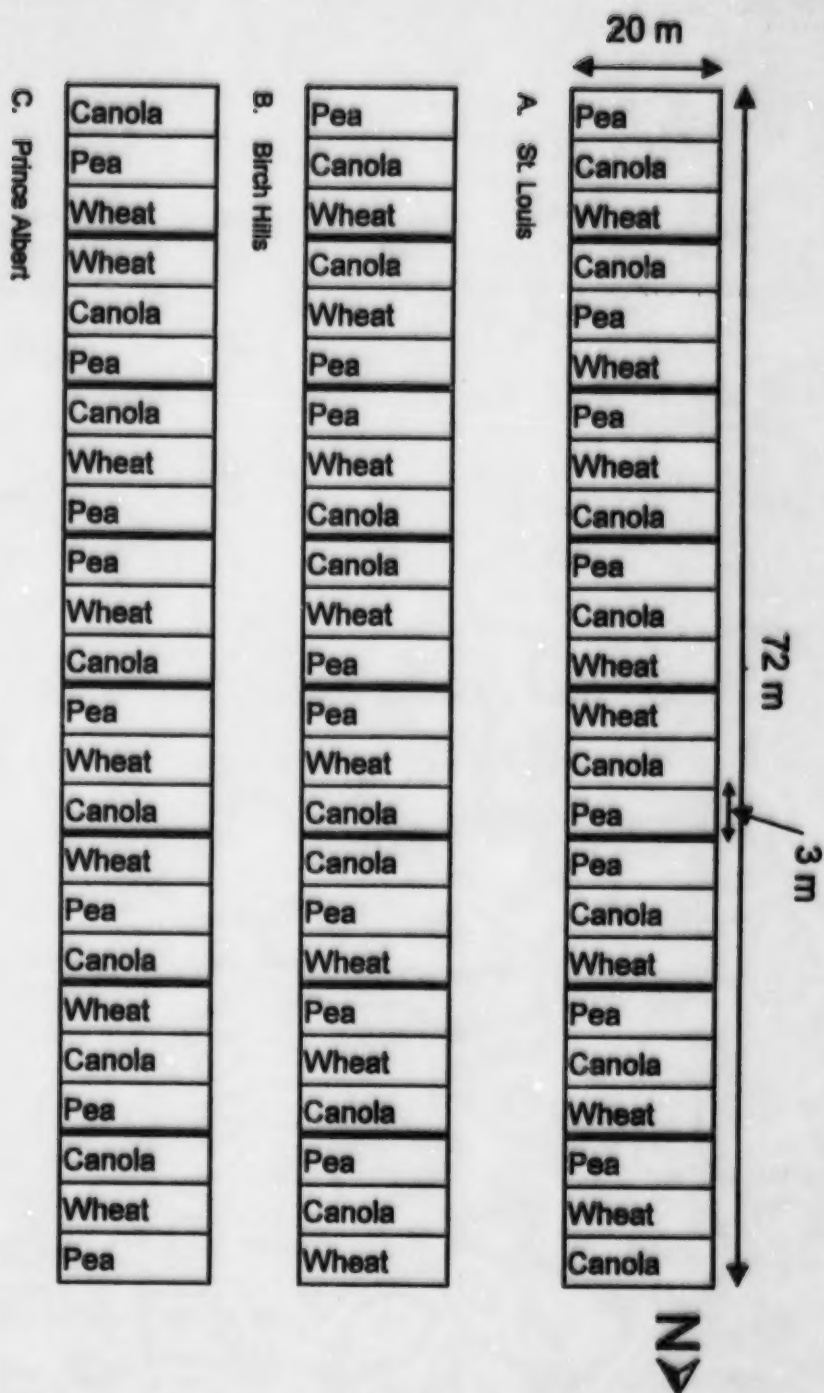


Figure 2. Plot plans for the small-plot study at the three field sites.

### ***<sup>15</sup>N Application and sampling:***

In the second rotation year, <sup>15</sup>N-enriched ammonium nitrate was applied to microplots within each plot to enable measurement of the size of the plant-available N pool integrated over time. With this procedure, the <sup>15</sup>N:<sup>14</sup>N ratio of the plant tissue varies inversely with the size of the unlabeled inorganic N pool available for plant uptake during the growing season (Senaratne and Hardarson, 1988). It is assumed that if the atom % <sup>15</sup>N excess of the wheat plants grown on pea or canola stubble do not differ from that of the wheat plants grown on wheat stubble, there is no extra N contribution to a subsequent wheat crop from pea and canola. Only the results for labeled residue are presented because the atom % <sup>15</sup>N excess for residue and grain were highly correlated with each other ( $P < 0.001$ ).

Field applications of <sup>15</sup>N involved applying double-labeled 10 atom % <sup>15</sup>N ammonium nitrate to 1-m<sup>2</sup> microplots at all sampling points. 0.5 kg N ha<sup>-1</sup> was dissolved in 8 L of water and the entire volume of solution uniformly applied to the microplot. The <sup>15</sup>N was applied shortly after the crop had emerged. At final harvest, subsamples of three or four plants were collected from the <sup>15</sup>N-labeled microplots and dried at 40 °C in a forced air oven. The samples were threshed by hand. The residue and grain were ground separately in a cyclone mill with a 0.4-mm screen. Residue samples were ground further in a rotating ball-bearing mill. The percentage of N and atom % <sup>15</sup>N content of a 1.00 ± 0.10 mg sample was determined using a continuous flow, isotope ratio mass spectrometer interfaced with a RoboPrep Sample Converter (Europa Scientific, Crewe, UK). The

working standard was  $^{15}\text{N}$ -enriched pea residue (atom %  $^{15}\text{N}$  excess = 0.2322; SD = 0.0019) and pea grain (atom %  $^{15}\text{N}$  excess = 0.1455; SD = 0.0029).

#### *Measurements:*

Composite soil samples were collected and analysed each spring and the recommendations for fertilizer application followed. Soil water and inorganic N content, atom %  $^{15}\text{N}$  excess, leaf and root diseases, densities of predominant weed species, and wheat grain yield and N concentration were measured at 150 sampling points in the second rotation phase (Fig. 1). Weed densities, root and leaf diseases and barley grain yield were measured at 90 sampling points in the third rotation phase. Sampling at 150 points was deemed to be excessive, so in the third rotation phase this was reduced to 90 sampling points per site. The middle six sampling points in each plot were sampled.

After herbicide applications, individual weed species were counted in four 0.25 m<sup>2</sup> quadrats at each sampling point. Only the most abundant species, i.e., wild oat (*Avena fatua* L.), Canada thistle [*Cirsium arvense* (L.) Scop.], and field horsetail (*Equisetum arvense* L.) were considered for further analysis. Common root rot (*Cochliobolus sativus* Ito & Kurib.) incidence was assessed between anthesis and maturity. Approximately 20 plants were excavated in a diagonal transect across each sampling point. Common root rot lesions on the subcrown internode were rated using a 0 to 4 scale (0 = 0%, 1 = 1 to 25%, 2 = 26 to 50%, 3 = 51 to 75%, and 4 = 76 to 100%). A mean of the 20 subsamples was calculated to obtain a single rating for each sampling point. Leaf disease [tan spot: *Pyrenophora tritici-repentis* (Died.) Drechs., and septoria leaf blotch: *Septoria avenae* Frank f. sp. triticea, Johns., *Septoria tritici* Rob. in Desm.,

and *Septoria nodorum* (Berk.) Berk.] lesions on the flag and upper leaves were rated near anthesis using a 0 to 11 scale (Table 2).

A 1-m<sup>2</sup> area was harvested at each sampling point in the second and third phases of the rotations at a time when producers would normally begin harvest operations. Samples were dried at 40°C in a forced air oven, threshed, and weighed to determine grain yields.

A meteorological station was installed at each site. Daily air temperature was measured with thermistors. Precipitation was measured with a tipping rain bucket gauge (model RG2501, Sierra Misco Inc., Berkeley, CA, USA). Meteorological data for the Prince Albert site was obtained from a meteorological station located one km from the site.

#### *Statistical Analyses:*

The influence of crop rotation and landform complex was assessed using analysis of variance (ANOVA). Data from each experimental unit was considered to be a repeated measure across the rotation phases. Blocking was considered as a random effect, and sites, crop rotations and landform complexes as fixed effects (Littel et al., 1996). Contrasts were used to make specific comparisons among the crop rotations. Treatment effects were declared significant at  $P=0.05$ . In cases where probability levels were between 0.05 and 0.10, the results are discussed as trends. Where  $P>0.10$ , results were considered to be insignificant. Significant landform complex effects, and interactions with crop rotation, for wheat grain yield and grain N concentration, were investigated further by including the other variables responding to the same effect or interaction as covariables in the same ANOVA model. Results from the covariance ANOVA were

**Table 2. Scale used to rank the severity of common root rot.**

| Scale (0-11) | Leaf area exhibiting leaf-spotting symptoms (%) |        |       |
|--------------|-------------------------------------------------|--------|-------|
|              | Lower                                           | Middle | Upper |
| 0            | 0                                               | 0      | 0     |
| 1            | 0-1                                             | 0      | 0     |
| 2            | 2-5                                             | 0      | 0     |
| 3            | 6-10                                            | 0      | 0     |
| 4            | 6-10                                            | 0-1    | 0     |
| 5            | 11-25                                           | 2-5    | 0     |
| 6            | 26-50                                           | 6-10   | 0     |
| 7            | >50                                             | 6-10   | 0-1   |
| 8            | >50                                             | 11-25  | 2-5   |
| 9            | >50                                             | 26-50  | 6-10  |
| 10           | >50                                             | >50    | 11-25 |
| 11           | >50                                             | >50    | 25-50 |

considered significant when: (i) the covariable(s) was significant at  $P=0.05$ ; and (ii) a previously significant treatment effect for the univariate ANOVA was no longer significant at  $P=0.05$  for the covariance ANOVA. A significant result implied that the landform effect for the covariables explained the variation associated with a particular treatment effect on grain yield and N concentration. Weed density data were transformed (natural logarithm) prior to all analyses to reduce the influence of non-normal data distributions.

The second component of the analysis included a repeated statement that fitted an exponential geostatistical function to the residual covariance (Gotaway et al., 1997). Covariance estimates for the residual covariance, effect of block, and the geostatistical function of the residual covariance were compared to assess the effectiveness of the experimental design.

## **Results and discussion:**

### ***Growing conditions:***

Growing conditions at the three sites are presented in Table 3. In general, growing conditions at St. Louis and Birch Hills, were dry with nearly normal temperatures. Compared to the long term average for this area of 200.7 mm of rainfall in June, July and August (Environment Canada, 1980), rainfall in 1997 was well below normal for these same months. Except in August, average daily temperatures were approximately 0.5 °C above normal. In August, temperatures were approximately 2 °C below normal. In contrast, the Prince Albert site in 1998, was wetter and hotter than the long term average. The long term average precipitation at Prince Albert for June, July

**Table 3. Precipitation and air and soil temperatures at the field sites in the second rotation phase.**

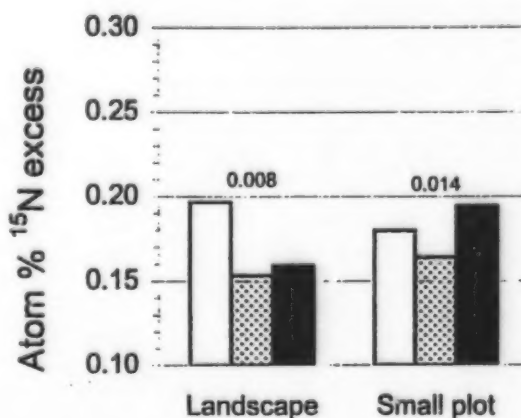
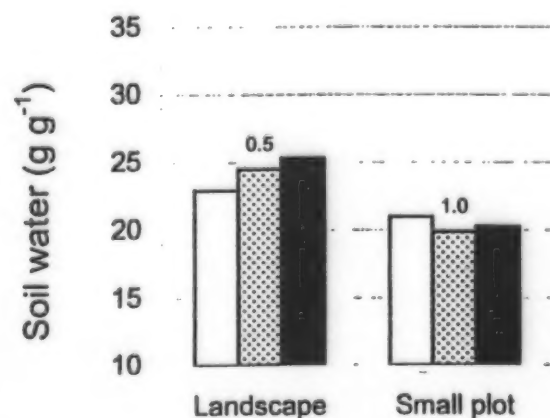
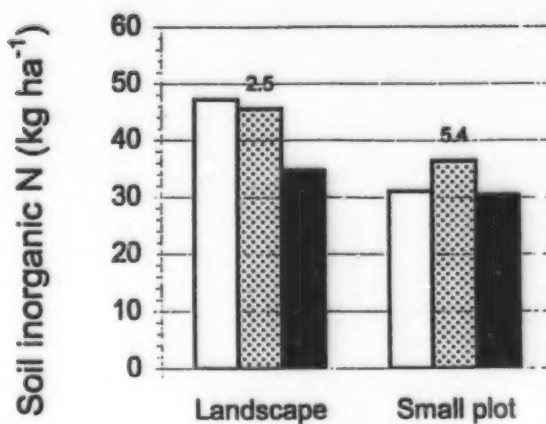
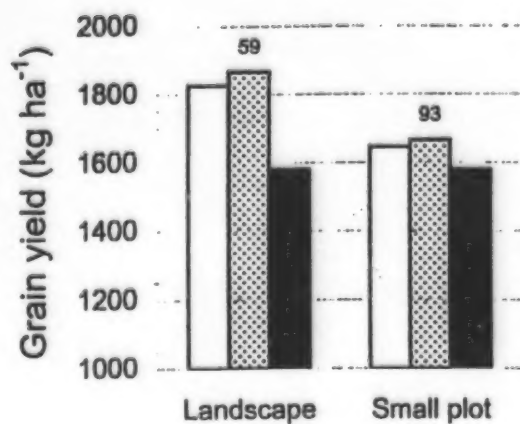
|                             | Air Temperature<br>(°C) |         | Soil Temperature<br>(°C) |         | Precipitation<br>(mm) |
|-----------------------------|-------------------------|---------|--------------------------|---------|-----------------------|
|                             | Mean                    | Maximum | Mean                     | Maximum | Cumulative            |
| <b>St. Louis (1997)</b>     |                         |         |                          |         |                       |
| June                        | 16.0                    | 21.7    | 17.3                     | 21.0    | 76.8                  |
| July                        | 18.6                    | 26.3    | 17.0                     | 19.3    | 38.0                  |
| August                      | 14.4                    | 22.6    | 14.2                     | 16.9    | 10.6                  |
| <i>Total</i>                |                         |         |                          |         | 125.4                 |
| <b>Birch Hills(1997)</b>    |                         |         |                          |         |                       |
| June                        | 16.2                    | 21.8    | 17.1                     | 18.7    | 60.9                  |
| July                        | 18.9                    | 26.7    | 17.8                     | 19.2    | 13.2                  |
| August                      | 14.0                    | 22.0    | 15.2                     | 16.5    | 22.1                  |
| <i>Total</i>                |                         |         |                          |         | 96.2                  |
| <b>Prince Albert (1998)</b> |                         |         |                          |         |                       |
| June                        | 14.8                    | 21.9    | 13.9                     | 14.9    | 89.0                  |
| July                        | 18.7                    | 25.3    | 18.3                     | 19.1    | 163.7                 |
| August                      | 19.1                    | 27.5    | 17.6                     | 18.4    | 32.4                  |
| <i>Total</i>                |                         |         |                          |         | 285.1                 |

and August is 186.5 (Environment Canada, 1980), approximately 100 mm below the rainfall for these months in 1998. Furthermore, daily temperatures for July was nearly 1.5 °C above normal and for August 3.7 °C above normal. At Prince Albert, these conditions normally should be conducive to disease development. On the other hand at St. Louis and Birch Hills, the dry conditions would be expected to keep diseases in check.

#### *Rotation effects:*

All three of the study sites exhibited the same tendency with respect to wheat grain yields from the different rotations. Analysis of variance did not identify a site by rotation interaction ( $P=0.54$ ) and hence, results for all three of the sites are combined. Wheat grain yield was higher in the pea-wheat and canola-wheat rotations compared with the wheat-wheat rotation (Fig. 3). There was no difference between the pea-wheat and canola-wheat rotations. The yield increase due to including a broadleaf crop (either pea or canola) in rotation was about 200 kg ha<sup>-1</sup>, or an approximately 12.5 % increase. An extensive examination of the Manitoba crop insurance database indicated that the average yield benefits from growing wheat after pea was 11 % and the benefit from growing wheat after canola was 8 % compared to when wheat was grown after wheat (Bourgeois and Entz, 1996). Related studies reported that yields of barley and wheat following pea can increase by more than 20 % compared to when a cereal was grown after a cereal (Wright, 1990; Evans et al., 1991; Smiley et al., 1994).

The higher yields in the two broadleaf rotations compared to the wheat-wheat rotation was somewhat more pronounced in the landscape-scale study than in the small-plot study ( $P=0.084$ ). None of the soil and plant factors measured consistently explained



Study Scale

Study Scale

Figure 3. Rotation effect on grain yield and soil factors for landscape and small plot studies in the second rotation year. Results for the three sites are combined. Numbers on the graphs are lsd ( $P=0.05$ ) □ pea-wheat ▤ canola-wheat ■ wheat-wheat

the higher grain yields observed in the pea-wheat and canola-wheat rotations compared to the wheat-wheat rotation between the two study approaches. In the landscape-scale study, lower soil inorganic N (Fig. 3), and higher leaf diseases and wild oat infestations (Fig. 4) occurred in the wheat-wheat rotation. There was no difference among rotations in the incidence of common root rot (Fig. 4). Of these factors, ANOVA identified only leaf diseases as a possible factor contributing to the rotation effect on yield ( $P=0.033$ ). In the small-plot study none of the factors measured consistently corresponded with the lower yields in the cereal rotation (Figs. 3 & 4).

Another study investigating the rotation effect of wheat grown after a pea crop compared to wheat grown after a wheat crop showed a 34 % larger rotation effect on grain yield using a landscape-scale approach compared to a small-plot approach (Stevenson and van Kessel, 1996a). Differences between landscape and small-plot approaches are probably due to the lack of independent sampling units in the small plot study. For example, crop diseases were demonstrated to vary across space at distances much greater than the distance between two small plots (Larkin et al., 1995; Madden and Nutter, 1995). It is likely that wind dispersal of leaf disease spores and weed seeds, and vegetative propagation of weeds among small plots could confound the rotation effect in the small-plot study.

Atom %  $^{15}\text{N}$  excess in the plant provides an indication of N availability to the succeeding crop. With this procedure, the  $^{15}\text{N}:^{14}\text{N}$  ratio of the plant tissue varies inversely with the size of the unlabeled inorganic N pool available for plant uptake during the growing season (Senaratne and Hardarson, 1988). It is assumed that if the atom %  $^{15}\text{N}$  excess of the wheat plants grown on pea or canola stubble do not differ from that of the

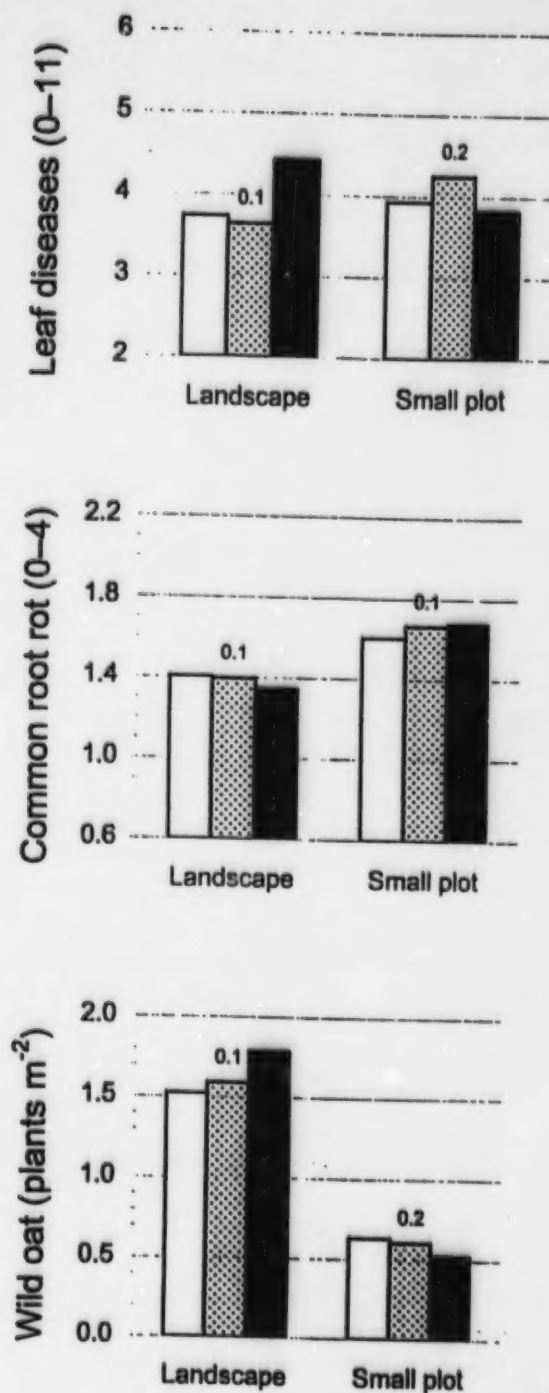


Figure 4. Rotation effect on diseases and weeds for landscape and small plot studies in the second rotation year. Results for the three sites are combined. Numbers on the graphs are lsd ( $P=0.05$ ) □ pea-wheat ▤ canola-wheat ■ wheat-wheat

wheat plants grown on wheat stubble, then there is no extra N contribution to a subsequent wheat crop from the pea and canola. Conversely, the higher atom %  $^{15}\text{N}$  excess measured in the wheat plants grown on pea stubble in the landscape-scale study, compared to wheat grown on canola or wheat stubble, indicates that more N was available to the wheat grown following pea in rotation (Fig. 3). Analysis of variance identified atom %  $^{15}\text{N}$  excess as a possible factor contributing to the higher grain yields in wheat grown following the broadleaf crops ( $P=0.014$ ).

In the small-plot study, atom %  $^{15}\text{N}$  excess was no larger from the pea-wheat rotation than the other rotations (Fig. 3) and was in fact slightly larger in the wheat-wheat rotation than the two broadleaf rotations. However, ANOVA did not identify a significant rotation effect in the small-plot study ( $P=0.40$ ). The smaller number of measurements made in the small-plot study (72 vs. 150) may have reduced experimental precision and the ability to detect the rotation effect. Furthermore, because soil N is very mobile, perhaps extra N made available by the pea crop moved out of the range of the small plot. Additionally, any tillage operations are more likely to mix soils in adjacent plots in a small plot study than in larger plots. In short, lateral transfer of N between small plots is much more likely to occur than transfer between large plots.

In addition to affecting grain yields, grain quality was affected by the different crop rotations. Grain N and total N concentrations were higher in the pea-wheat and canola-wheat rotations compared with the wheat-wheat rotation in both the landscape-scale and small plot studies (Fig. 5). There were no differences in grain N and total N between the pea-wheat and canola-wheat rotations, hence, the higher N accumulation was not due exclusively, to a N-benefit provided by the pea. While grain N content reflects

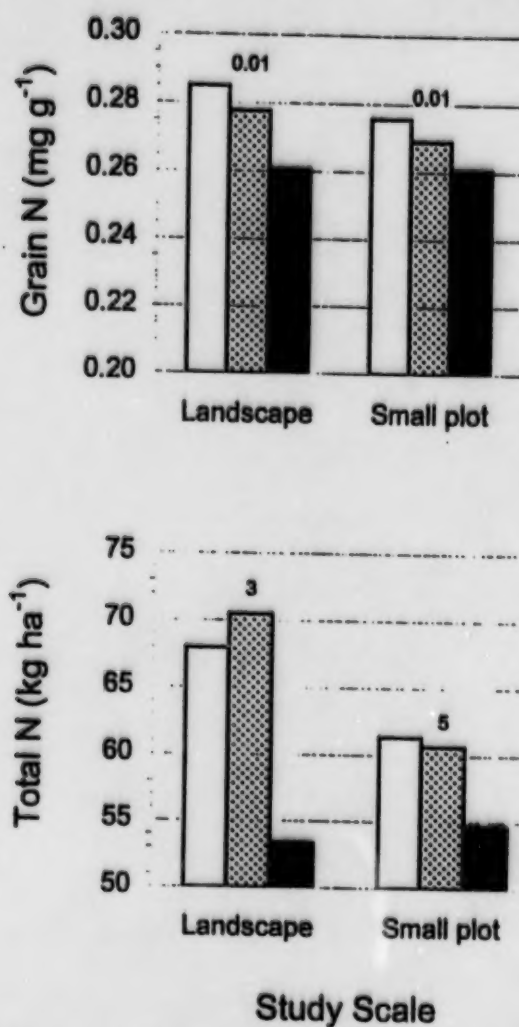


Figure 5. Rotation effect on grain and total N for landscape and small plot studies in the second rotation year. Results for the three sites are combined. Numbers on the graphs are  $\text{isd}$  ( $P=0.05$ ) □ pea-wheat    ▨ canola-wheat    ■ wheat-wheat

protein quality in the grain, it is difficult to interpret what total N concentration means to the plant. Clearly, wheat grown after wheat took up less total N than wheat grown after canola or pea (Fig. 5), but grain yield and grain N content were not affected to the same extent. Furthermore, the reason for the extreme differences in total N content between wheat grown after wheat and the broadleaf crops is not clear. One possibility is that the root systems from the preceding broadleaf crop affect soil structure in such a way as to promote more extensive growth of the subsequent wheat crop, so the wheat plants are able to explore a larger volume of soil than when they are grown after a wheat crop. Another possibility is that microorganisms associated with the root systems of the broadleaf crops may affect more efficient uptake of N in the subsequent crop. Neither of these factors were explored in the present study.

The rotation effect on grain N was the same for the landscape-scale and small plot study, but the effect on total N tended to be more pronounced in the landscape-scale study ( $P = 0.087$ ). Other researchers also have reported increases in grain N contents when wheat or barley was preceded by pea in rotation rather than another cereal (Wright 1990, Evans et al., 1991). However, reports of no rotation effect on grain N content also have been made (Stevenson and Van Kessel, 1996a).

In the past, yield advantages associated with including legumes in intensive cereal rotations were attributed to additional N being made available to the succeeding cereal. The additional N was associated with N fixed by the legume and remaining in the soil in roots and shoot residue and subsequently decomposed, as well as the lower C:N ratio for the legume residue (25:1 to 40:1 for legumes compared to 70:1 to 100:1 for non-legumes) promoting mineralization of the legume residue, thereby increasing the availability of the

N to the next crop in rotation. However, such a N-benefit can not explain the yield advantage obtained from including non-legume broadleaf crops in rotation with cereals. There are several mechanisms by which non-N benefits can be obtained including but not restricted to reduced incidence of root and leaf diseases in subsequent crops (Dyke and Slope, 1978; Pedersen and Hughes, 1992; Smiley et al., 1994; Bailey and Duczek, 1996, Stevensen and van Kessel, 1996a) and reduced weed populations (Dyke and Slope, 1978; Blackshaw et al., 1994; Stevenson and van Kessel, 1996b)

An analysis of covariance was performed in an attempt to identify those measured variables that explained the rotation effect on grain yield (Table 4). Only those variables that were significant for the study by rotation interaction (i.e., atom %  $^{15}\text{N}$  excess,  $P=0.033$  and leaf diseases,  $P<0.001$ ) were considered in the covariance analysis. At all of the sites, very little of the rotation effect on grain yield could be attributed to atom %  $^{15}\text{N}$  excess (N-benefit) and leaf diseases (non-N benefit). At St. Louis and Prince Albert, only 12 % of the total rotation effect could be attributed to these two factors; 88 % remained unaccounted for. At St. Louis the rotation effect on yield was split equally between the N and non-N effects. At Prince Albert, the majority (11 %) of the identified effect was attributed to leaf diseases. At Birch Hills, leaf diseases played a larger role in determining grain yield associated with the different rotations, but still only accounted for 27 % of the rotation effect. Stevenson and van Kessel (1996) found that leaf diseases explained the majority of the rotation effect of wheat grown after pea compared to wheat grown after wheat.

Results of the analysis of covariance for grain N content are reported in Table 5. As was the case with grain yield very little of the rotation effect on grain N content was

**Table 4. Analysis of covariance for the effect of rotation on grain yield.**

| Covariables<br>included in<br>analysis | ----- Grain yield -----                   |                     |                                        |
|----------------------------------------|-------------------------------------------|---------------------|----------------------------------------|
|                                        | Rotation effect                           |                     |                                        |
|                                        | Rotation effect<br>without<br>covariables | with<br>covariables | Explained by<br>covariable<br>analysis |
|                                        |                                           |                     |                                        |
|                                        | <i>P</i> †                                | <i>P</i> ‡          | % §                                    |
| <i>St. Louis</i>                       |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | < 0.001                                   | 0.002               | 6                                      |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     | 6                                      |
| Unaccounted                            |                                           |                     | 88                                     |
| <i>Birch Hills</i>                     |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | < 0.001                                   | 0.007               | 1                                      |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     | 27                                     |
| Unaccounted                            |                                           |                     | 72                                     |
| <i>Prince Albert</i>                   |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | < 0.001                                   | < 0.001             | 1                                      |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     | 11                                     |
| Unaccounted                            |                                           |                     | 89                                     |

**Table 5. Analysis of covariance for the effect of rotation on grain N content.**

| Covariables<br>included in<br>analysis | Grain N content                           |                     |                                        |
|----------------------------------------|-------------------------------------------|---------------------|----------------------------------------|
|                                        | Rotation effect                           |                     |                                        |
|                                        | Rotation effect<br>without<br>covariables | with<br>covariables | Explained by<br>covariable<br>analysis |
|                                        |                                           |                     |                                        |
|                                        | <i>P</i> †                                | <i>P</i> ‡          | %§                                     |
| <i>St. Louis</i>                       |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | < 0.001                                   | < 0.001             | 0                                      |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     | 2                                      |
| Unaccounted                            |                                           |                     | 98                                     |
| <i>Birch Hills</i>                     |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | < 0.001                                   | 0.002               | 0                                      |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     | 7                                      |
| Unaccounted                            |                                           |                     | 93                                     |
| <i>Prince Albert</i> ¶                 |                                           |                     |                                        |
| Atom % <sup>15</sup> N                 | 0.378                                     |                     |                                        |
| excess                                 |                                           |                     |                                        |
| Leaf diseases                          |                                           |                     |                                        |
| Unaccounted                            |                                           |                     |                                        |

† Probability level for grain N content having a significant rotation effect without including the covariables in the analysis.

‡ Probability level for grain yield having a significant rotation effect including the covariables in the analysis.

§ Percentage of the grain N content explained by the covariables.

¶ Grain N content was not affected by crop rotation at Prince Albert.

explained by the variables included in the analysis. Only those covariables that had a significant rotation effect were included in the analysis. At St. Louis, only 2 % of the rotation effect was explained, and this was attributed to leaf diseases. Similarly, at Birch Hills, 7 % of the rotation effect on grain N content was explained by leaf diseases. A rotation effect on grain N content was not present at Prince Albert and hence an analysis of covariance was not performed for data at this site. None of the rotation effect on grain yield was attributable to N availability at either St. Louis or Birch Hills. Thus, even though a rotation effect existed for grain N content, the primary cause of the effect could not be identified.

Interestingly, when atom %  $^{15}\text{N}$  excess and leaf diseases were included in the analysis of variance, compared to when they were not included in the analysis, the probability level associated with the analysis increased (i.e., became less significant) (Table 4). This means that these two variables were ineffective in explaining the rotation effect on grain yield. It appears that perhaps there were other factors that were not measured that contributed to the higher grain yields associated with including broadleaf plants in rotation compared to the pure cereal rotation. Although factors like other nutrients (P, K, S) (Stone and Buttery, 1989; Bullock, 1992) or possibly soil physical properties (Bullock, 1992; Karlen et al., 1994) or microbial factors associated with the different root systems (Cook, 1992), may have contributed to the rotation effect on grain yield, it seems unlikely that these factors would be more influential than N-benefits from the succeeding legume or interruptions in disease/weed cycles. Perhaps it is the cumulative effect of a large number of factors that contribute to the rotation effect for grain yield.

Alternatively, it is possible and probably more likely, that the large amount of variation across the sites interfered with the detection of the factors causing the differences in grain yield. Patchy responses, like those experienced with pest infestations, are not captured well by ANOVA. For example, crop-weed interference occurred at only a small proportion of the footslope sampling points in the wheat-wheat rotation at Birch Hills but certainly did affect yield at these sampling points. Because of these types of patchy responses, the ANOVA results were biased (based on a small area of the landscape) despite the fact that exploratory analyses (results not shown) indicated that the ANOVA assumptions were not seriously violated. If the response function explaining yield varies with space (in one area a certain set of explanatory factors exist and in another area another set exist, etc.) the result is that the covariance associated with each response function across the entire site will underestimate the importance in a given spatial unit. This underestimation ultimately will mean that the residual covariance will be inflated. This is probably why the covariance ANOVA was uninformative and the univariate ANOVA was more informative. For example, areas with common root rot incidence may have reduced grain yield in one or more of the crop rotations in a 0.5 to 1 ha section of the study site. Areas with higher soil resource availability may have increased grain yield in one or more of the crop rotations 100 m down the field and so on. Averaging across patchy responses and functional sub-units, as is done with ANOVA, probably will confound these relevant sources of landscape-scale variation.

Moreover, blocking, randomization, and accounting for spatial structure in the residual covariance may not be effective tools at reducing the amount of unexplained variation from ANOVA. An examination of covariance estimates associated with

different components of the ANOVA for grain yield indicate that overall blocking was ineffective and that most of the variation in the data was associated with residual or unexplained variation (Table 5). Blocking was only effective (but only slightly) at the Prince Albert site. In short, ANOVA did not effectively control for or explain variation in grain yield. A previous study, conducted on two adjacent 1 ha areas of land, clearly demonstrated the landscape-scale variation for grain yield in different crop rotations, and the factors controlling this variation (Stevenson and van Kessel, 1996). In this instance, ANOVA probably was successful because the study areas were too small for patchiness and different functional sub-units to be important but large enough that any the individual sites were independent of one another. In short, ANOVA may not be appropriate for agronomic research conducted at the scale that is most relevant to producers – the sites are too large.

In addition, the basic approach of ANOVA may not be appropriate for agronomic research conducted at the landscape-scale. The ANOVA approach was developed to remove or control 'spurious' sources of variation (i.e., landscape-scale variation), when in fact this variation is important in determining the agronomic response. Also, a landform effect is only deemed to be important when it is detected at the chosen significance level, when in reality we know that landscape-scale variation is always present.

Any benefits of including pea and canola in rotation with cereals, did not persist into the third phase of the rotation. Barley grain yield did not differ among crop rotations ( $P=0.58$ ) (Fig. 6). The lack of crop rotation response on grain yield occurred in both the landscape-scale and small plot studies at all three sites. Of all of the factors measured, wild oat densities showed the most variation between rotations in the third year (Fig. 6)

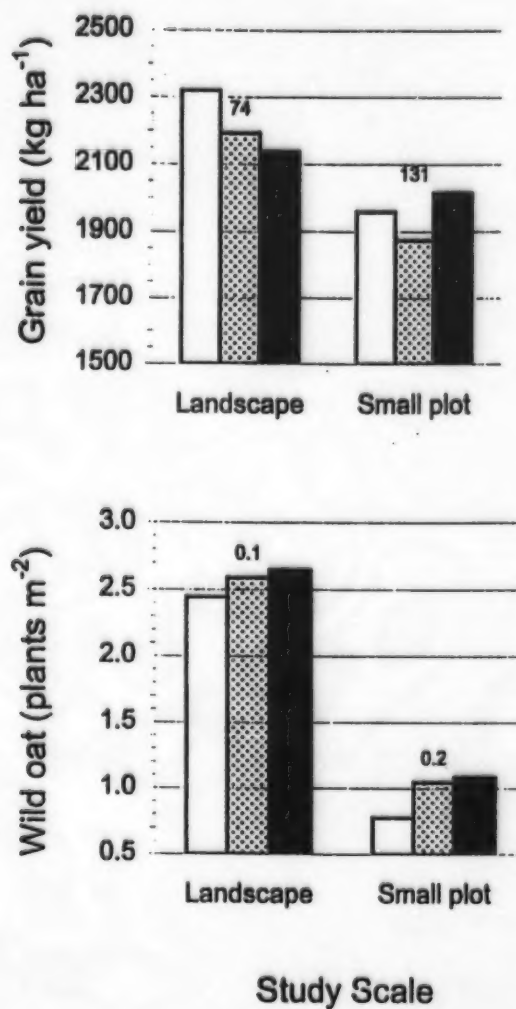


Figure 6. Rotation effect on grain yield and weeds for landscape and small plot studies in the third rotation year. Results for the three sites are combined. Numbers on the graphs are lsd ( $P=0.05$ )  pea-wheat-barley  canola-wheat-barley  wheat-wheat-barley

but did not vary predictably with the different crop rotations ( $P = 0.14$ ). None of the other variables measured showed a rotation effect into the third year. Unlike the present study, other studies have shown that a rotation effect persisted into the third year, in that wheat yields were still higher in a pea-barley-wheat rotation compared to a barley-barley-wheat rotation (Wright, 1990).

The magnitude of yield and quality advantages obtained from growing a cereal after a broadleaf crop rather than a cereal crop appear to be highly dependent on the particular study and the associated growing conditions (Wright, 1990; Evans et al., 1991; Campbell et al., 1992). For example, Wright (1990) reported that differences in growing conditions over three years and between two sites resulted in barley yields that ranged from a reduction of 12 % to an increase of 45 % in a pea-barley rotation compared to a barley-barley rotation.

#### *Landscape-scale study:*

##### Differences between landscape positions:

The influence of landscape position on grain yield and its interaction with the different crop rotations was only addressed in the landscape-scale study and hence a discussion of these results follow. The small plot study was performed on relatively uniform (flat) plots with no differentiation between landscape positions.

All three of the sites behaved quite differently with respect to the effect of landform position on wheat yield in the second phase of the crop rotation. At the St. Louis site, grain yield was higher on the footslopes than on the shoulders for all three crop rotations (Fig. 7;  $P < 0.001$ ). The difference between grain yield was no more

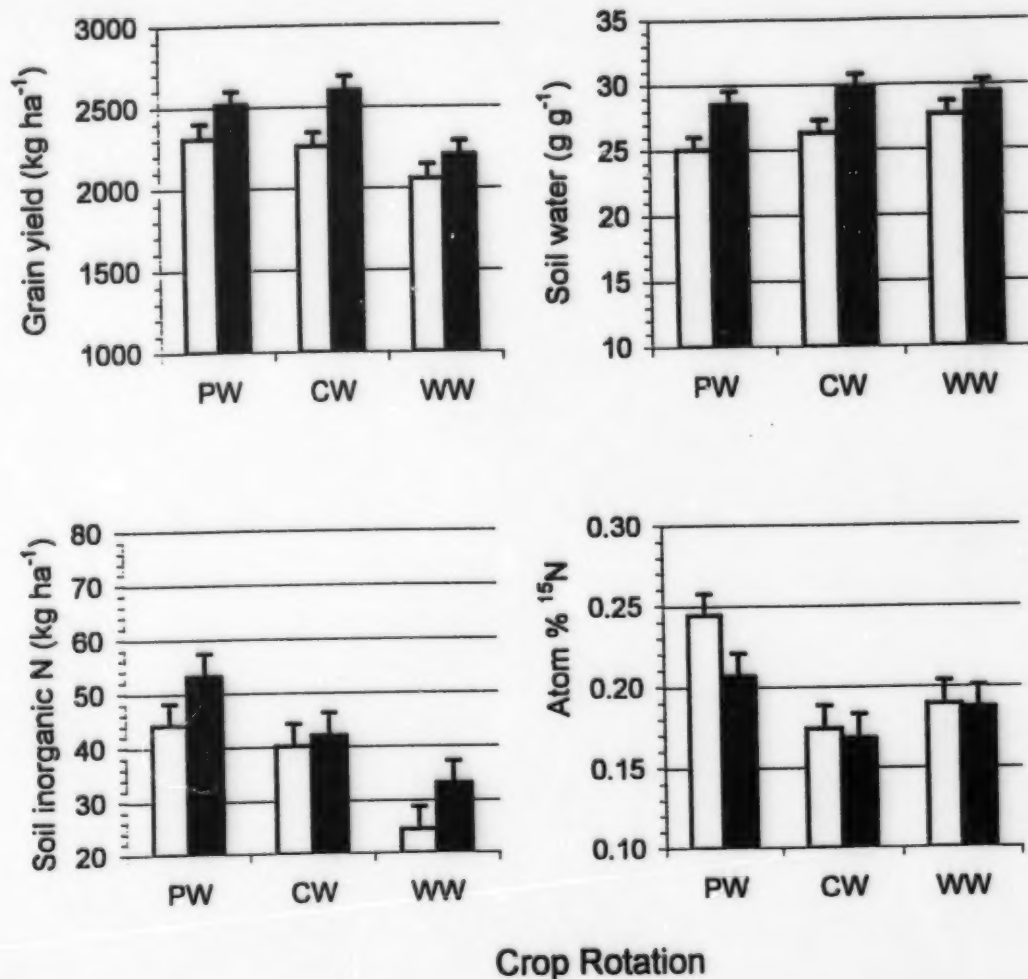


Figure 7. Landscape effect on crop and soil factors under three rotations at St. Louis.  shoulder  footslope.

pronounced in the two rotations that included broadleaf plants (pea and canola) than in the cereal rotation (wheat) ( $P=0.285$ ). The landform effect corresponded with higher soil water ( $P<0.001$ ), and inorganic N at sowing ( $P=0.022$ ; Fig. 7). However, incidence of common root rot ( $P=0.027$ ; Fig. 8) also tended to be higher on the footslopes than on the shoulders, which logically should translate into lower yields in the footslopes, not higher yields as were observed. Although, wild oat densities also appear to show a landform effect (Fig. 8), they were not statistically significant ( $P=0.317$ ).

Analysis of covariance did not confirm that the higher soil resource availability in the footslopes was responsible for the corresponding yield effect ( $P=0.285$ ). This covariance ANOVA did not include root rot incidence because of the illogical nature of including it.

At the Birch Hills site, only the wheat-wheat rotation showed a slight landform effect for grain yield in the second rotation year ( $P=0.05$ ). At this site, grain yield was lower on the footslopes than on the shoulders (Fig. 9). Soil water content prior to sowing ( $P=0.001$ , Fig. 9), wild oat density ( $P=0.045$ ) and Canada thistle density ( $P=0.001$ ) (Fig. 10) also was higher on the footslopes in the pea-wheat and wheat-wheat rotation compared to the shoulders at Birch Hills and tended to be more extreme in the wheat-wheat rotation. However, analysis of covariance did not identify any of these factors as contributors to the reduced grain yields on the footslopes. The nature of the differences in grain yields between footslopes and shoulders could not be discerned at this site.

Interestingly, in the pea-wheat rotation, weeds (wild oat and Canada thistle) and leaf diseases were considerably higher on the footslopes than on the shoulders but did not translate into lower yields on the footslopes. However, had the footslopes not had these

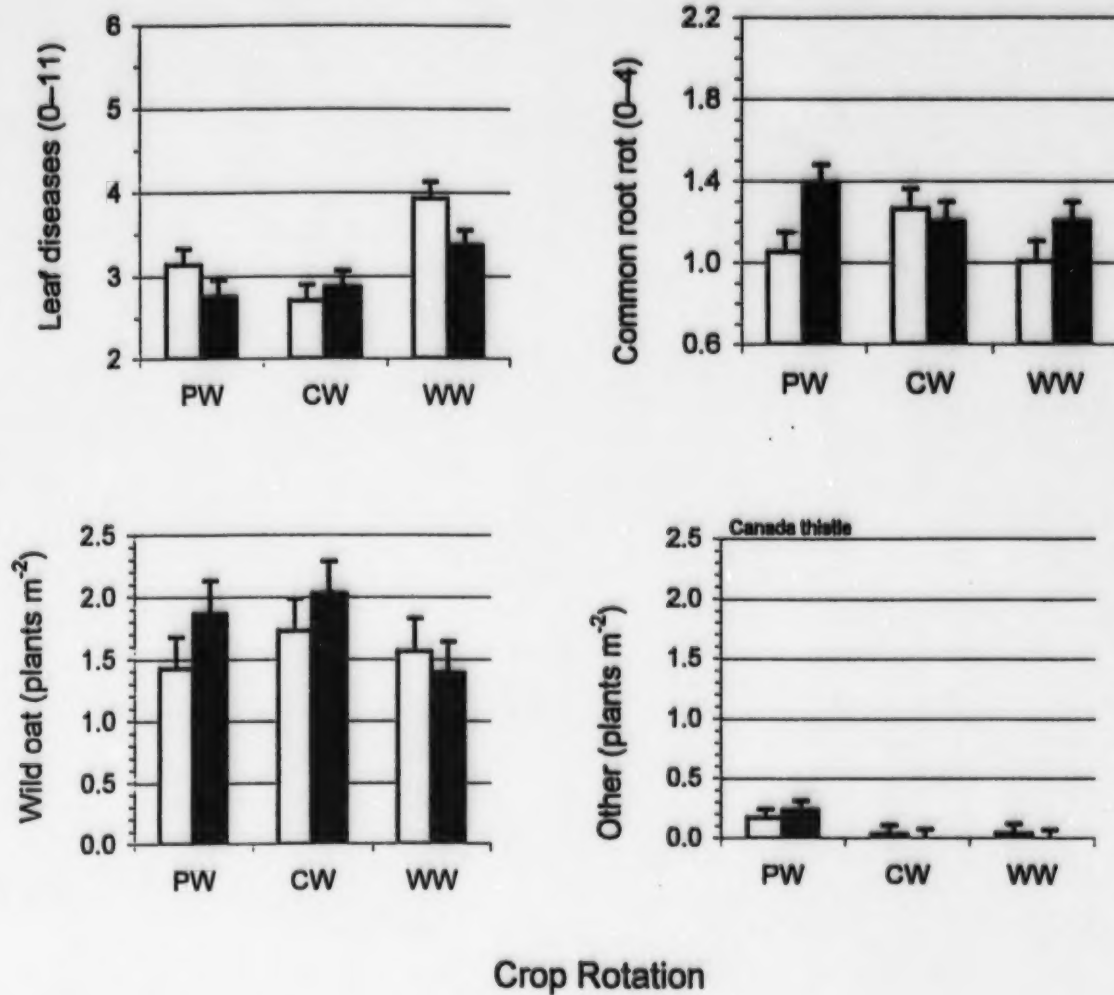


Figure 8. Landscape effect on diseases and weeds under three rotations at St. Louis.  
 □ shoulder      ■ footslope

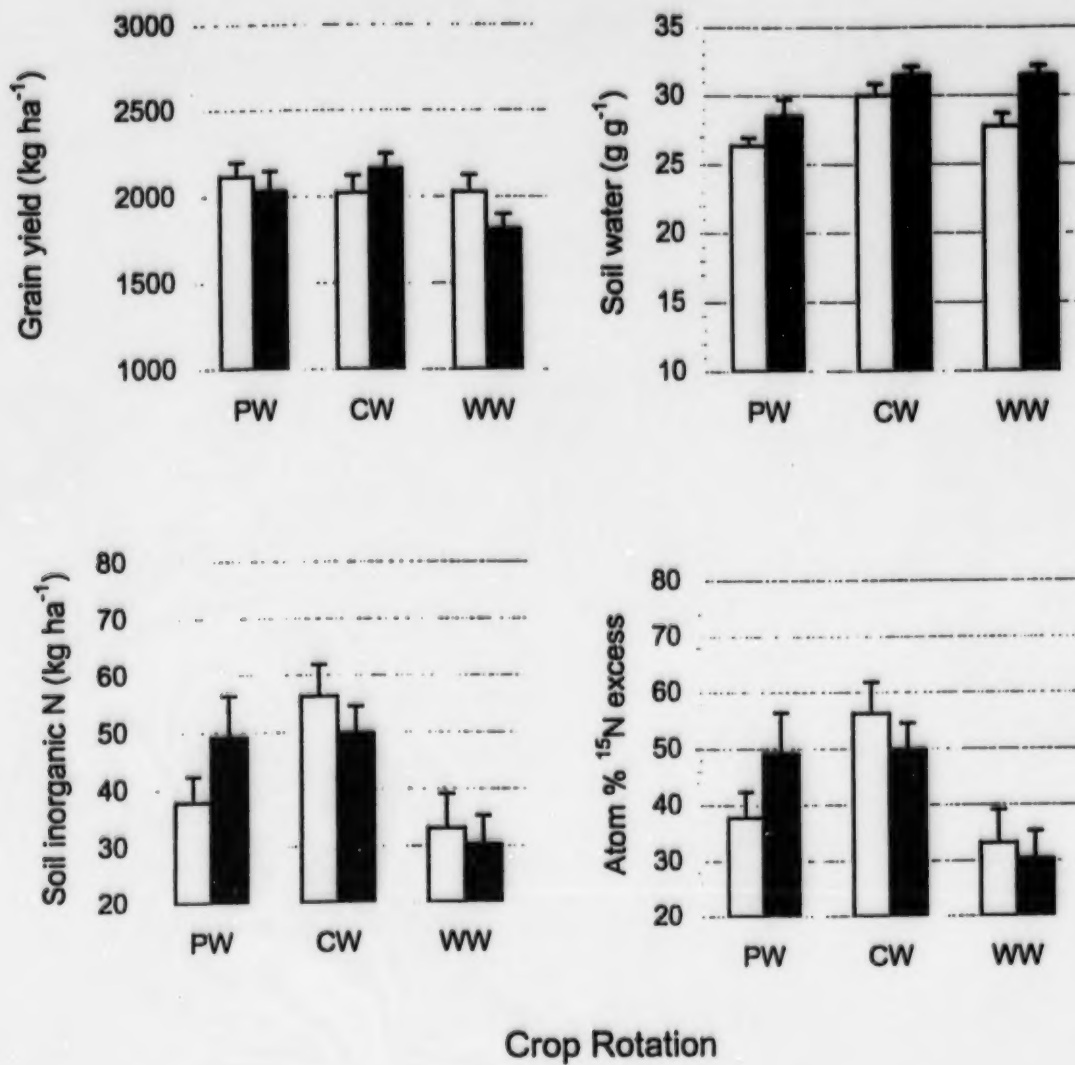


Figure 9. Landscape effect on crop and soil factors under three rotations at Birch Hills.

□ shoulder      ■ footslope

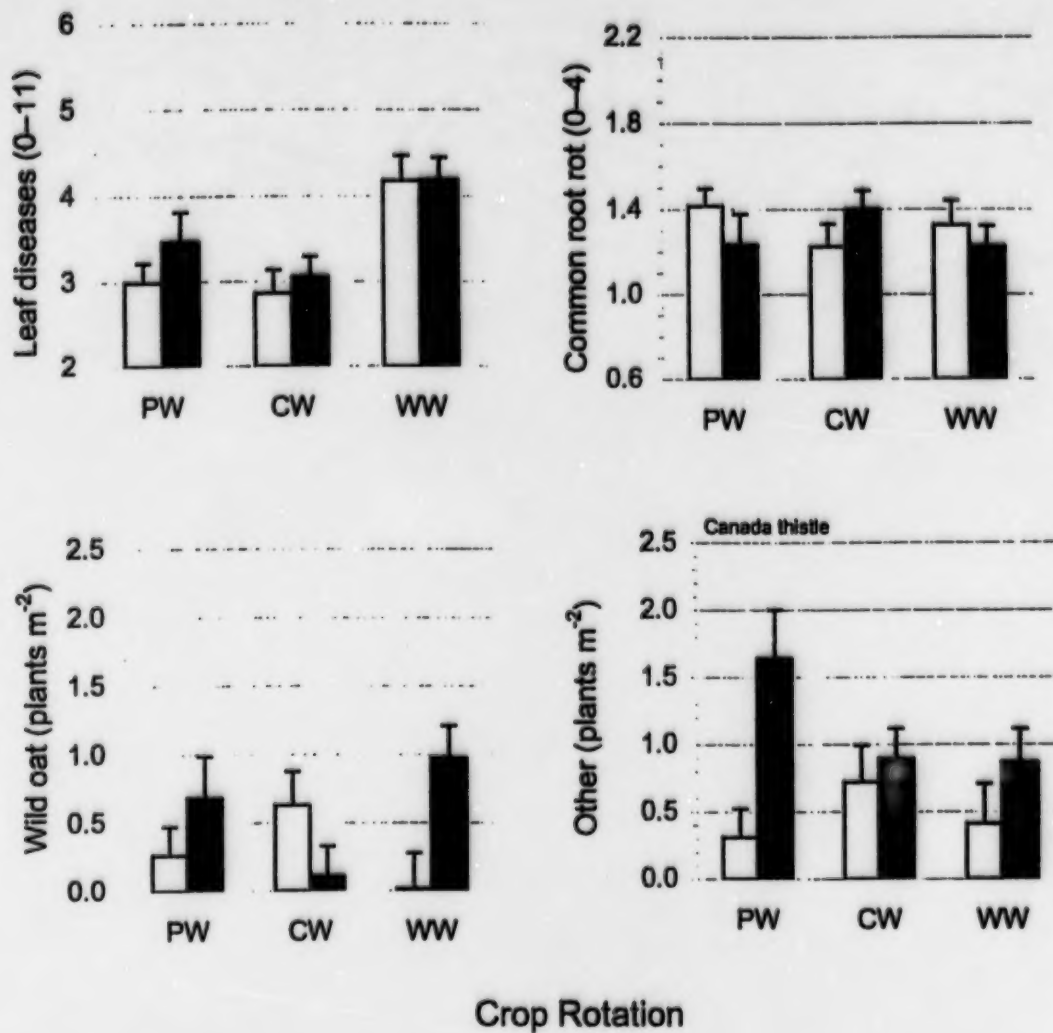


Figure 10. Landscape effect on diseases and weeds under three rotations at Birch Hills.

□ shoulder      ■ footslope

relatively high weed and disease populations, higher yields may have been expected on the footslopes compared to the shoulders. This seems especially pertinent, considering the higher overall availability of resources (soil water, inorganic N and atom %  $^{15}\text{N}$  excess – Fig. 9) on the footslopes compared to the shoulders of the pea-wheat rotation. Higher yields in footslopes compared to shoulders were reported by Stevenson and van Kessel (1996) and Beckie and Brandt (1997) and was associated with greater resource availability in the footslopes. In contrast, Solohub (1997) reported no consistent yield difference between footslope and shoulder positions.

At the Prince Albert site in the second rotation year, no differences between grain yields on the footslope and shoulder positions were detected for any of the three rotations ( $P=0.995$ , Fig. 11). This is somewhat surprising because soil water ( $P<0.001$ ) and soil inorganic N ( $P<0.001$ ) were considerably higher on the footslopes than on the shoulders in all of the rotations. However, compared to the St. Louis and Birch Hills sites, soil water at sowing was very low at the Prince Albert site regardless of the landscape position. It is very difficult to attribute a level of importance for the contribution of soil water at sowing to final grain yields since this is a single point measurement in time and has little relation to precipitation throughout the growing season. Indeed, at the Prince Albert site growing season precipitation in 1998 was well above normal (Table 3) and could (and probably would) have overshadowed the effect of soil water just prior to seeding. Similarly, because the wheat crops at all of the locations were fertilized with either  $55 \text{ kg N ha}^{-1}$  (St. Louis and Birch Hills) or  $60 \text{ kg N ha}^{-1}$  (Prince Albert), the contribution to final grain yield of any pre-seeding inorganic N is questionable. Results from an AFIF funded project under the leadership of Dr. D. Pennock (Soil Science, U of

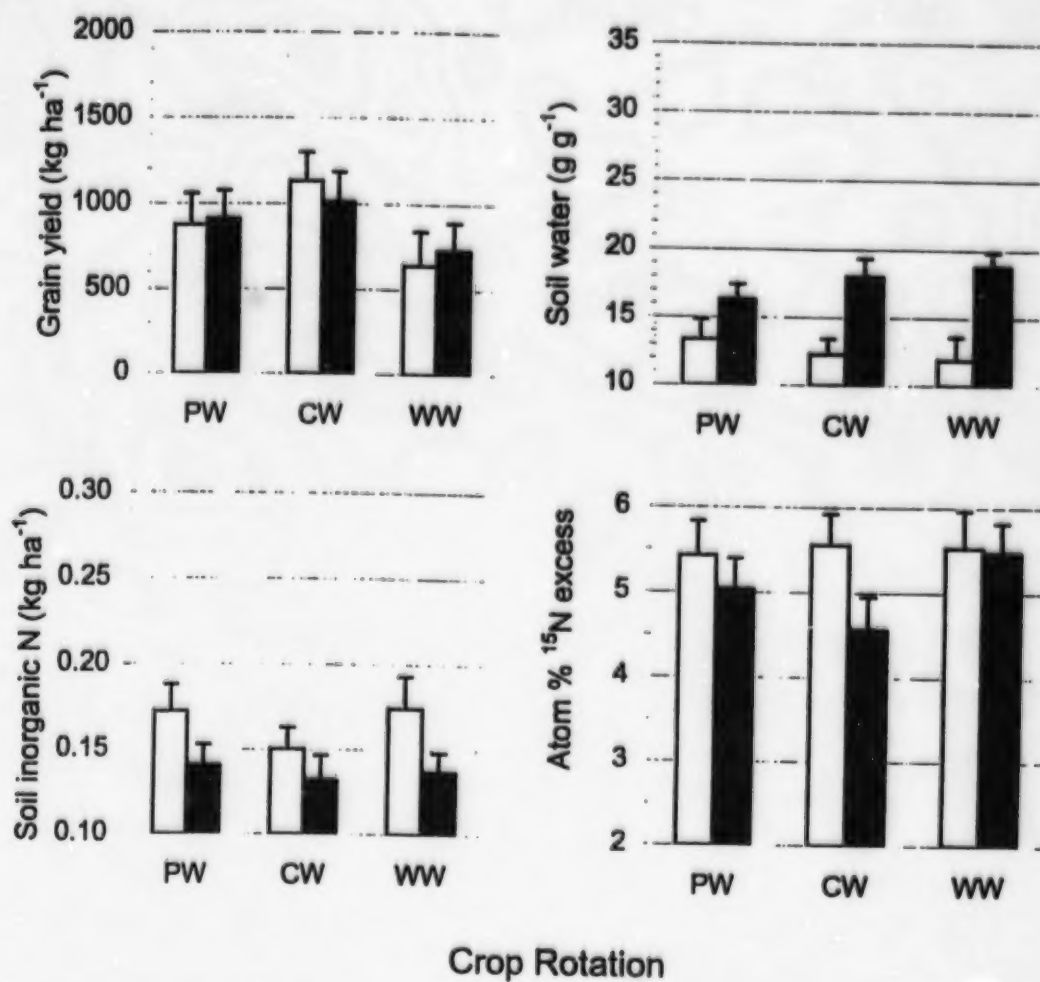


Figure 11. Landscape effect on crop and soil factors under three rotations at Prince Albert  
 □ shoulder      ■ footslope

S) that is investigating landscape effects on yield in a variety of crops at six sites across Saskatchewan, indicate that soil inorganic N is not an effective predictor of yield under any of the study circumstances (D. Pennock, personal communication). Furthermore, at Prince Albert, no consistent pattern emerged for disease and weed incidence that could explain the lack of landform response for grain yield (Fig. 12). For example, in the pea-wheat rotation, leaf diseases, wild oat and field horsetail densities tended to be low in the footslopes, but root rot incidence was high in the footslopes compared to the shoulders. In the wheat-wheat rotation, there were no differences between leaf diseases or weed densities, but root rot incidence was lower in the footslopes compared to the shoulders. In short, landform had no consistent, measurable effect on grain yields at this site.

In the third (barley) rotation phase, differences in response variables on the different landscape positions, due to the different crop rotations were much less evident (Fig. 13) than in the second rotation year. Of the variables measured only weed densities showed any landform effect. At St. Louis, grain yields tended to be slightly higher on the footslopes in the pea-wheat-barley ( $P=0.07$ ) rotation than the other rotations but did not correspond with contrasting landform effects for wild oat density ( $P=0.12$ , Fig. 13). In the other two rotations, wild oat densities were higher on the footslopes compared to the shoulders. It appears that high wild oat densities on the footslopes in the canola-wheat-barley and wheat-wheat-barley rotations suppressed grain yields somewhat, so that yields were lower on the footslopes of these two rotations compared to the pea-wheat-barley-rotation. There were only very low levels of root and leaf diseases at any of the sites and no differences among the different rotations.

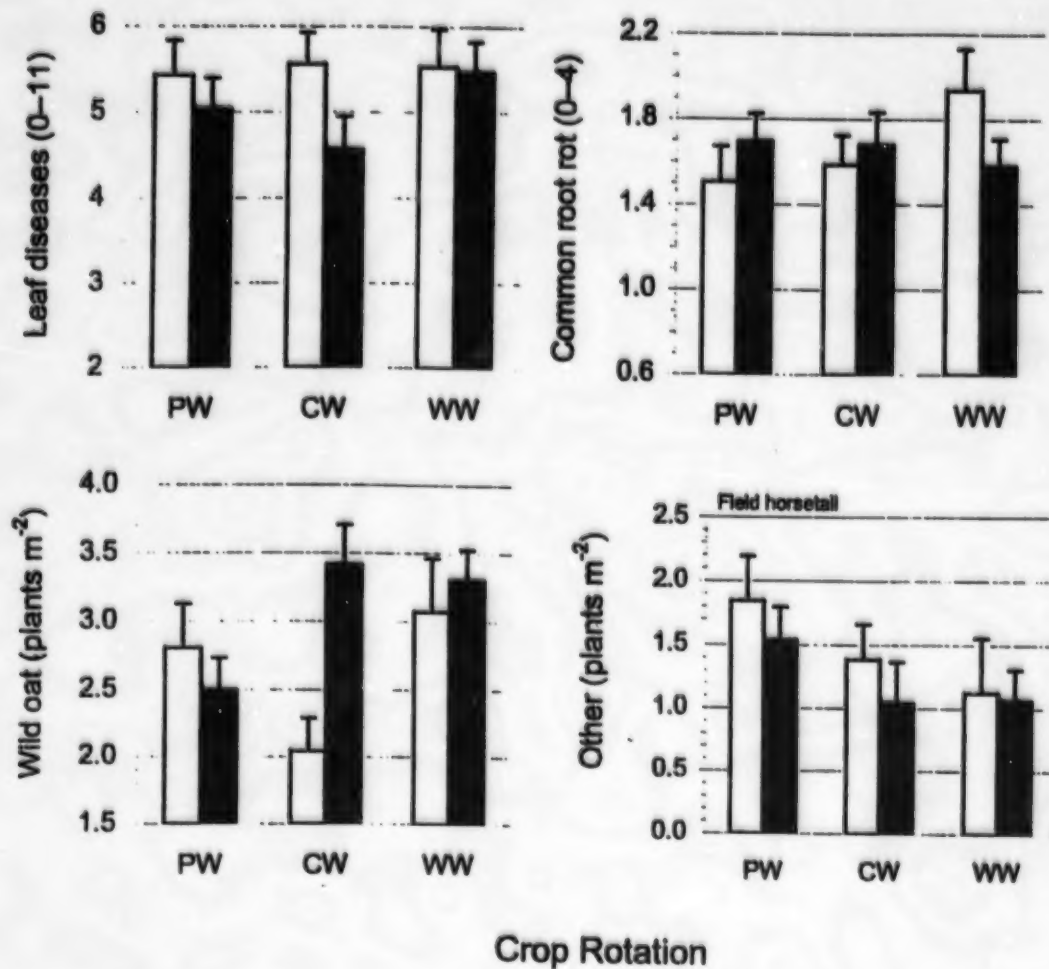


Figure 12. Landscape effect on diseases and weeds under three rotations at Prince Albert.  
 □ shoulder      ■ footslope

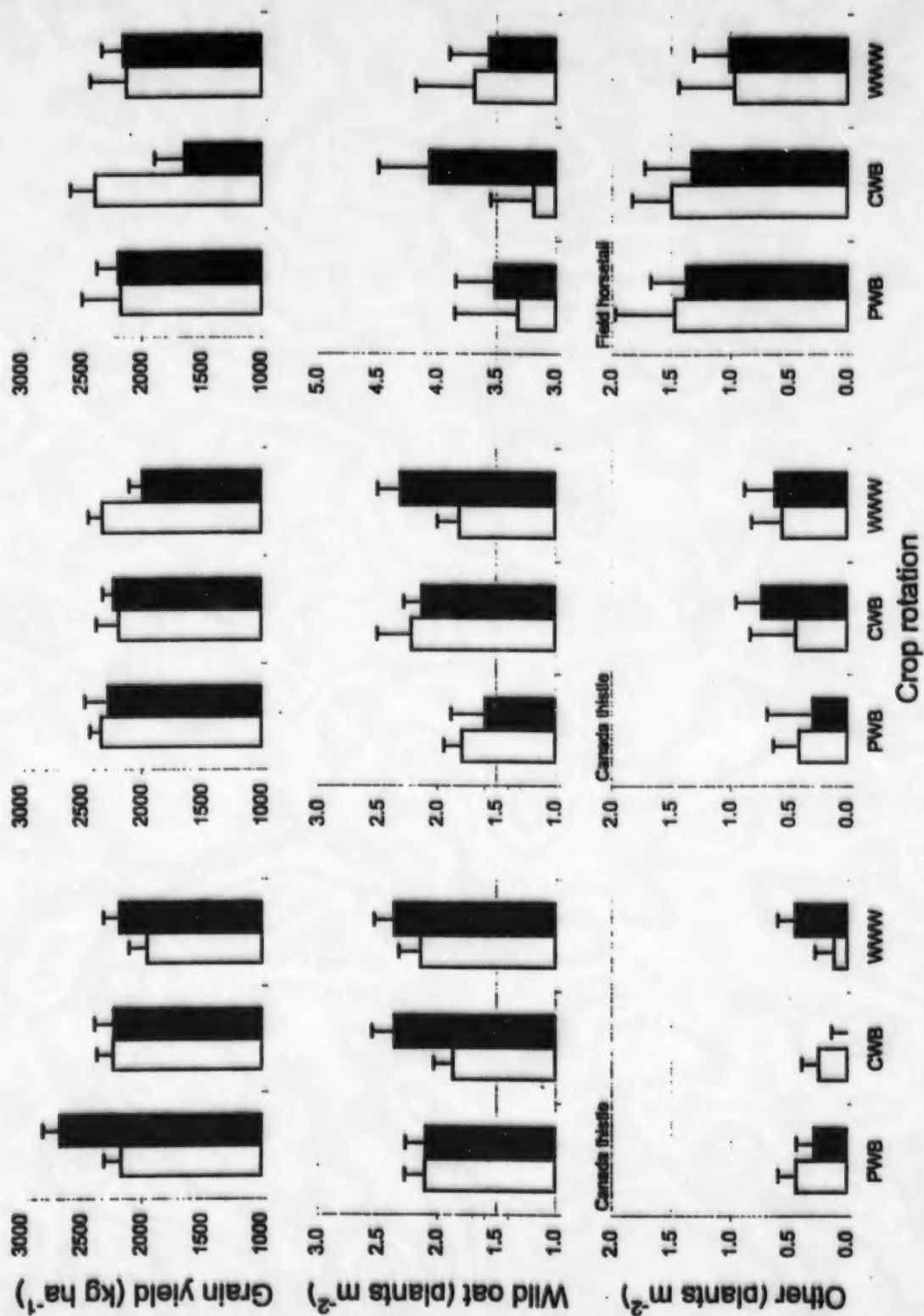


Figure 13. Rotation effect on grain yield and weed densities in the third rotation year.

At Birch Hills there was no overall difference in barley grain yield between the landscape positions ( $P=0.12$ , Fig. 13). However, in the wheat-wheat-barley rotation, grain yield was lower on the footslopes compared to the shoulders and corresponded with higher wild oat infestations ( $P=0.043$ ).

Similarly at Prince Albert, there was no overall difference in barley grain yield associated with landscape position ( $P=0.248$ , Fig. 13). However, at this site the canola-wheat-barley rotation showed lower grain yields on the footslopes than on the shoulders and seemed to be associated with higher wild oat densities on the footslopes compared to the shoulders, even though no overall landscape effect on weed densities could be identified (wild oat,  $P=0.30$ ; field horsetail,  $P=0.80$ ).

#### Conclusions:

In general, including either pea or canola in rotation with spring wheat provided a similar benefit to both yield and protein content in the second rotation year crop (spring wheat). Both the pea-wheat and canola-wheat rotations resulted in higher grain yields (ca. 12.5%) and grain N content in the succeeding wheat crop than the wheat-wheat rotation. However, the benefit was not extended to the third rotation year (barley) crop. Although a clear yield and grain N benefit were identified in the broadleaf rotations, only a very small percentage of the benefit could be conclusively attributed to either a N-benefit or a non-N benefit. At the Birch Hills site 28% of the benefit was identified with 27% of the total caused by non-N factors, specifically and decrease in the incidences of leaf diseases. At the Prince Albert and St. Louis sites, the explainable benefit was even lower, only 12%. At Prince Albert most (11%) was due to lower leaf disease incidences

and only 1% due to a N-benefit, whereas at St. Louis the benefit was split equally between N- and non-N benefits.

A comparison of small-plots with the landscape-scale plots indicated that the landscape-scale study was better able to identify benefits conferred by the different rotations and better able to determine the causes of these benefits. However, compared to other reports in the literature and landscape-scale studies performed in our laboratory, the landscape-scale approach used in the present study was less effective in identifying and attributing the cause of the benefits attained from the different crop rotations. It appears that the plot size used in the present study (4 ha) was too large for this type of study. Other landscape-scale studies typically used 1 ha sized plots. The larger land base appears to have introduced a lot of variability that was not appropriately controlled or accounted for using the traditional statistical procedures (i.e., analysis of variance).

Furthermore, an analysis of landscape elements within the landscape-scale study did not identify specific soil and plant attributes associated with the landform elements that predictably affected yields and grain protein in the different crop rotations. Each of the three study sites responded very differently to the landform elements. At Birch Hills, the footslopes consistently supported higher yields than the shoulders, but at Prince Albert and St. Louis, no consistent pattern existed. It appears that very patchy responses across the landscape interfered with the ability to detect differences between landscape positions.

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**d) Personnel**

Marie Boehm (50 %) year 1 & 2

Craig Stevenson (100 %) year 1

(50%) year 2

(25%) year 3

Melissa Forester (Zink) (100%) years 1 & 2

**e) Equipment - none**

**f) Project Developed Materials**

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**g) Project Photos - none**

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**i) Expense Statement**

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